Forest soil rehabilitation with woodwaste:

Characteristics of rehabilitated and untreated soils.

Submitted to CJSS – please do not cite for information only

Short title: **Soil rehabilitation with woodwaste**

C.E. Bulmer[1] and K. Venner[2]

[1]*BC Ministry of Forests, Research Branch, 3401 Reservoir Road, Vernon, BC Canada V1B 2C7.*

[2]*Scopeworks Engineering Ltd., 2335 – 23rd Avenue SW, Calgary, AB Canada T2T 0W3.*

105-05668/

ABSTRACT

We evaluated soil conditions of rehabilitated log landings in the Interior Douglas fir biogeoclimatic zone of British Columbia during the first 3 years after treatment. Rehabilitation treatments included combinations of tillage and the addition of either stockpiled topsoil or one of three woody organic amendments: hog fuel, sort yard waste, and a wood waste - biosolids compost. The woody amendments were either applied as mulch, or incorporated into the surface soil layer after tillage. Tillage and addition of woodwaste reduced soil bulk density and increased the carbon content of the soils. Daytime soil temperatures in mid summer were lower under a hog fuel mulch than for the other treatments, and the plots receiving hog fuel also had higher soil moisture content. During the second year after treatment, soil mechanical resistance increased from minimum values in the spring to reach maximum levels in summer, then declined again in the fall. Soil mechanical resistance for untreated soils, and those that were simply tilled, exceeded 2500 kPa for much of the growing season, while plots receiving wood waste had lower mechanical resistance. Soil rehabilitation with wood waste appears to improve soil conditions for common properties that are likely to affect plant growth.

INTRODUCTION

In British Columbia, soil rehabilitation practices are used to mitigate soil degradation during forestry operations. Rehabilitation usually involves tillage to loosen compacted soils (Plotnikoff et al. 2002), and may include steps to restore organic matter and nutrients lost during road and landing construction (Sanborn et al. 200x). Strategies for restoring soil organic matter include (1) conservation and replacement of organic – rich surface soils, (2) establishing grass and legume cover crops that enhance organic matter inputs to soil, and (3) addition of organic amendments derived either from waste logs, stumps, treetops and branches in close proximity to the site, or from external sources.

Past studies to investigate the effects of tillage and organic amendments on compacted soils have produced mixed results. While some studies have indicated that tillage can improve soil conditions and forest productivity (Andrus and Foehlich 1983; Bulmer 2000), others trials demonstrated little improvement (e.g. McNabb 1994). The addition of organic waste materials to soils where organic matter has been depleted or lost also had positive effects on soil conditions (Sanborn et al. 200x; Zebarth et al. 1999) and plant growth (Gouin et al. 1978; Ringe and Graves 1990), but the responses were dependent on the characteristics of the organic material.

Organic amendments vary in their physical and chemical composition (Land Resources Network 1993), and include materials that are nutrient-poor such as wood waste or sort-yard waste (Campbell et al 1994), and those that are nutrient-rich such as manure, municipal biosolids, or compost (Bulmer 1998).

Addition of chipped logging debris was associated with reduced seedling performance in Norway spruce (Hallsby 1995) and lodgepole pine (*Pinus contorta*) (Bulmer 2000). The reduced seedling performance was attributed to site-specific limitations associated with soil temperature, nutrient availability, or water retention.

Effects of amendments partly depend on the method of application, and other aspects of the treatment. Placing amendments on the soil surface, i.e. as a mulch, moderates soil temperature and prevents evaporative water loss (Brady, 1984), slows decomposition of the material, and reduces potential problems of low plant nutrient availability associated with nutrient immobilization. Nutrient limitations may also be overcome by the addition of N fertilizer or nutrient rich amendments. For example, the nutrient content of untreated sort yard waste increased following composting with a nutrient-rich material, such as manure and municipal biosolids (Campbell et al. 1994). Also, Wardle et al. (1995) found that the C concentration of pine sawdust declined by 33-57% within 3 years. During the same period, N concentration increased from the original levels by 8-13 times, suggesting that the period of reduced N availability due to immobilization may have a similar duration, and negative effects on seedling establishment and growth could possibly be avoided by delaying plant establishment for a few years.

In the Okanagan Valley of British Columbia, several forest product manufacturing facilities produce wood wastes that may be useful as soil amendments. Log landings and roads associated with extensive forestry operations on the plateau lands surrounding the

valley are potential sites where the wood wastes could be used as soil amendments. In 1998, a trial was established to evaluate the effects of soil rehabilitation with excavator tillage, and applications of topsoil, sort yard waste, hog fuel, and a biosolids-wood waste compost. This paper describes the soil conditions on the plots and some of the implications for forest productivity.

MATERIALS AND METHODS

Site description:

The study area is located near the town of Okanagan Falls in the Okanagan Valley of British Columbia (49° 18 ° N and 119 ° 26 ° W) at an elevation of 1100 masl. The sites lie within the dry mild subzone of the Interior Douglas-fir (IDFdm1) biogeoclimatic zone (Lloyd et al. 1990), where mean annual precipitation averages 505 mm, with 169 mm falling during the growing season. Mean annual temperature is 3.8 ° C (Lloyd et al. 1990).

The study was established on three log landings that were constructed as part of access development for forest harvesting in 1976. Prior to establishing plots and carrying out the rehabilitation treatments establishing the treatments in 1998, vegetation on the landings consisted mostly of grasses. Natural regeneration of tree seedlings was negligible, even though there were many mature trees adjacent to the landings, which appeared to provide a source of seed.

Soil texture was determined at three locations on each landing and ranged from silt loam to sand (Soil Survey Staff 1975), with the most common texture being sandy loam. Subsoil (20-40 cm) clay content was less than 5 % for all landings, while surface soil (0-10 cm) clay content ranged from 2.5 - 20 %. Six of nine surface soil samples had less than 10 % clay.

Treatments

Treatments were applied in May 1998 to 8 by 10 m plots arranged in a randomized complete block design. Each landing represented one block. An excavator equipped with a single-tooth ripper was used to till the landing area to a depth of 75 cm. Amendments were applied either as surface mulch or blended in the surface soil with an excavator bucket to a depth of 25 cm (Table 1). The amendments consisted of one of three wood wastes (hogfuel, sort yard waste or biosolids), or topsoil material (Table 2). As part of a larger trial, forty lodgepole pine seedlings were planted within each plot at 2 m by 1 m spacing.

Hog fuel was composed almost entirely of wood and bark, and had the highest C content and the lowest bulk density of the amendments. It was similar to materials that could be produced in remote areas by chipping accumulated logging debris on roadsides and log loading areas. Sort-yard waste consisted of mineral soil mixed with wood, bark, needles and other debris that accumulated on the surface of truck loading and unloading areas. Sort-yard waste had the lowest C content and the highest bulk density of the amendments. The biosolids-wood waste compost used in this study was a mixture of

screened hog fuel and biosolids from the City of Penticton, British Columbia. The compost had low bulk density, intermediate C content, and much higher concentrations of N, P, and K than the other amendments (Table 2). The topsoil was collected from piles located around the perimeter of the landing and consisted of the surface layer of soil, organic matter and plants scraped from the area during landing construction.

Field and laboratory methods

Mineral soil samples were collected in 0.5 l cores from two depths (1.5-8.5 cm and 11.5-18.5 cm) adjacent to three randomly selected trees within each plot during September, 1998. Because the samples are thought to be representative of soil conditions over the 0-10 cm and 10-20 cm depths respectively, all data are reported in 10 cm depth increments. For plots receiving amendments as mulches, the sampling depths began at the top of the decompacted mineral soil. Fine fraction bulk density was determined after passing the sample through a 2 mm sieve (Culley 1993; Federer et al. 1993). Samples of the fine fraction (< 2 mm) were then used for subsequent determination of physical and chemical properties.

Soil texture was determined by the hydrometer method (Sheldrick and Wang 1993). Total C and N were determined by dry combustion using a Fisons NA-1500 elemental analyzer (Tiessen and Moir 1993; McGill and Figueirdo 1993). Mineralizable-N (Min-N) was determined from ammonium-N in a KCl extract of soil following a two-week anaerobic incubation at 30 °C (Bremner 1996). Sulfate-S was determined by ion chromatography after extraction with a solution of $NH_4Cl - Ca(H_2PO_4)_2$ (Kalra and Maynard 1991).

Available P was determined with the Bray P1 method (Kalra and Maynard 1991). Exchangeable cations (exch. K, Ca, and Mg) and CEC were determined after displacement with $BaCl_2$ (Hendershot and Duquette 1986), and pH was determined in water (Hendershot et al. 1993). Electrical conductivity (EC) was determined on a 1:2 soil water extract (Kalra and Maynard 1991) for selected soil samples, and no statistical analysis was carried out on the data.

On five occasions during the 2000 growing season, soil temperature was determined with a hand-held digital thermometer at a depth of 10 cm at three locations in each subplot. Measurements were taken between 10:00 hr and 17:00 hr, and took approximately 2 hours to complete a full set of measurements for all treatments on each landing. Temperatures reported here are thought to represent average daytime conditions on the sample days.

At the same locations and on the same dates as soil temperature measurements were carried out, volumetric water content and soil mechanical resistance were determined at 10 cm depth. Volumetric water content was determined using a ThetaProbe soil moisture sensor (Delta T Devices 1999). The ThetaProbe generates a 100 Mhz frequency signal, which extends to the soil through four metal rods, and forms a standing wave voltage, which is proportional to the apparent dielectric constant of soil, and to the volumetric water content.

A hand-pushed cone penetrometer (30 ^{o} cone angle; 4 mm diameter base) attached to a hand-held force gauge (Transducer Techniques Ltd. Temecula, California, USA) was used to determine soil mechanical resistance. A small excavation was created to a depth of 20 cm The probe was pushed horizontally through the soil of an undamaged face at a speed of approximately 15 mm s^{-1}, the average force required for the probe to penetrate was recorded over a distance of approximately 50 mm, with measurements beginning after the probe had penetrated approx 10 mm into the surface. Values for soil mechanical resistance reported here reflect an average of five readings obtained at each sampling point and time. It was not feasible to obtain values higher than approximately 9,000 kPa.

An automated climate station was installed on one landing in July 2000. Rainfall, air temperature, and solar radiation were recorded hourly, at the bulk density sampling points on selected treatment plots. Soil temperature and moisture were recorded using thermocouples and resistance blocks, respectively. Information was recorded through the later part of the 2000 growing season, and through most of 2001.

Soil water retention characteristics at 3-5 cm depth were evaluated on an undisturbed sample of mineral soil collected in a 0.038 l core from selected plots on one landing only. The undisturbed samples were equilibrated on a pressure plate apparatus at water potential of 5, 10, 33, 100, 300, and 1500 kPa, and the water content at each value of water potential was determined.

Maximum (Proctor) compaction levels were determined using ASTM method D698-00a (ASTM 2001) for samples collected at two locations on each landing. The samples were collected from areas that did not receive amendments, so are considered to represent conditions for untreated soils and those that were that were decompacted. Relative bulk densities for treatment plots were determined as the ratio of observed bulk densities to the maximum bulk density for samples with similar carbon content.

Data analysis

Data were analysed using analysis of variance (ANOVA). All ANOVA tests used the mixed procedure (SAS Institute Inc. 1988). Planned contrasts were used to test the effect of amendment, tillage and method of application (i.e. mulch vs. incorporated). Except where noted, a probability threshold of p=0.05 was used throughout the text for inferring statistical significance.

RESULTS AND DISCUSSION

Bulk density and water retention characteristics

Three months after the treatments were applied, mean soil bulk density of the fine fraction was highest in the untreated control plots (Figure 1; Table 3), and soils that received wood waste had lower bulk density than those that did not. Differences in bulk density between plots treated with the different wood wastes were not significant, but surface mineral soils for mulched plots had higher bulk density than those where the amendment was incorporated into the surface. Plots where topsoil was replaced also had lower bulk density than those that were simply decompacted.

Fine fraction bulk density was inversely related to soil C concentration (Figure 2). The increased C content associated with addition of organic amendments apparently contributed to reductions in bulk density, particularly for treatments DSI, DHI, and DCI, where amendments were incorporated into the surface soil layers. Federer et al. (1993) observed similar close associations between bulk density of forest soils and organic matter content and attributed the effect partly to different particle densities for mineral and organic soil components.

Evaluating whether soil bulk densities are growth-limiting requires consideraiton of properties such as soil texture and carbon content. For sandy-loam soils low in organic matter, Daddow and Warrington (1983) suggested that values of1600-1700 kg m^{-3} were associated with reduced plant growth. Average values in our study were below this level, but individual values obtained for some plots (DSS and U) were higher than 1600 kg m^{-3} (Figure 2).

The average maximum (Proctor) bulk density for untreated and decompacted soils was 1729 kg m^{-3}, and values for individual plots ranged from 1570 to 1840 kg m^{-3}. Relative bulk densities for untreated plots averaged 0.85 for surface soils and 0.82 for subsurface soils. For tilled plots, relative bulk density for surface soils averaged 0.75 and subsurface soils averaged 0.81. Carter (1990) observed that the grain yield of cereals was reduced when relative bulk density of fine sandy loam soils exceeded 0.84. High relative bulk densities indicate degraded soil structure where growing roots are expected to encounter

limitations imposed by one or more of water availability, aeration, or mechanical resistance (da Silva et al. 1997). Some of the untreated soils in our study, and soils that were simply decompacted had relative bulk density at or near values where impaired plant growth would be expected.

Water retention characteristics of the soils collected from one landing (Table 4) showed high point to point variation, likely reflecting differences in tillage consistency and amendment mixing. Although statistical analysis was not carried out on this limited data set, mean aeration porosity for each treatment was above 10 percent, which is considered the threshold above which soils may become susceptible to anaerobic conditions as a result of compaction (da Silva et al 1997).

Soil chemistry and nutrients

Carbon content at 0-10 cm and 10-20 cm was higher for plots receiving wood wastes than for soils that were simply decompacted (Tables 5, 6), and plots where compost was incorporated into the surface soil had higher C concentrations than those where the other wood wastes were incorporated. Concentrations of C in plots receiving topsoil tended to be higher than those that were simply decompacted (p=0.0517) at the 0-10 cm depth.

Variation in C content resulted partly from incomplete mixing during incorporation of the amendments. Occasional pockets were encountered during sampling that were enriched in organic matter compared to the surrounding soil. Another factor affecting the C content of the soils was the particle size of the amendment. The compost was dominated

by small particles, many of which passed the 2 mm sieve used to prepare the soil samples for analysis. Hog fuel contained a high proportion of wood particles larger than 2 mm, while the sort-yard waste had a range of particle sizes (data not shown). Therefore, although the DSI, DHI, and DCI treatments all received similar amounts of added C, fine fraction soil samples from the DCI treatment had higher C content.

At all soil depths, total N concentration was significantly higher for plots receiving compost (Tables 5, 6). For soils with no wood waste amendment and those treated with sort yard waste and hogfuel, N concentrations were low and were not significantly affected by treatment. This absence of a significant difference reflected the low N concentration of the amendments.

Differences in CN ratio for the amended soils also reflect the differences in the wood wastes, with plots receiving compost and sort yard waste generally having lower CN ratios compared to plots receiving hog fuel. The difference arose due to the high C (45 %) and low N (0.18%) content of hogfuel, compared to the high N (0.95%) and low C (23.6%) concentrations of compost and the low N (0.13%) and low C (21.3%) concentrations of sort yard waste. Such differences were most apparent where the amendments were incorporated into the surface soils. Contrasts for CN ratio of surface soils (Table 6) included a significant difference between plots receiving wood waste compared to those that were simply decompacted.

Differences in concentrations of min-N, P, SO_4-S and exch K between the treatments were generally not significant, except for the plots that received compost (Table 7), which had higher concentrations of these nutrients (Table 5).

Because wood wastes are typically low in N, their decomposition in the soil can cause immobilization of soil N, and reduced N availability for plants (Beauchemin et al. 1990). Zeng et al. (1993) observed low NO_3 and NH_4 concentrations in soils receiving log yard fines. In our study, min N levels of surface soils in plots treated with hog fuel or sort yard waste were not significantly different from those that did not receive wood waste ($p=0.1804$). The results presented here do not support the conclusion that addition of the wood wastes led to N immobilization; However, alternative explanations suggest that either (1) incomplete mixing of the wood wastes with the mineral soil created a heterogeneous soil material where variability masked any effects of any N immobilization, (2) soil physical conditions on the plots interacted with the effect of the soil amendments on min-N, and/or (3) the short time frame and dry soil conditions (Figure 4) between treatment and soil sampling precluded the development of major differences.

Powers (1980) concluded that mineralizable N values below 12 ppm were associated with N limitation as a determining factor affecting site productivity for *Pinus ponderosa* on volcanic soils in northern California, but that site productivity on granitic soils was not related to mineralizable N values below 12 ppm. For all sites, mineralizable N values higher than 20 were associated with soils that were not expected to respond to N

fertilization. In our study, min N levels for many of the plots were within the range (i.e. <12 ppm) where some N limitation of productivity may be expected. The min N values we observed were similar to values obtained for rehabilitated soils in other parts of British Columbia (Bulmer and Krzic, 2003).

Differences in exch K concentrations between the treatments were not significant when compared to between treatments except when the DCI treatment was compared against the DSI and DHI treatments (Table 7). Plots receiving compost had high levels of exch K and Mg (Table 8). Significant contrasts for pH (data not shown) at 0-10 cm included hog vs. sort yard waste ($p=0.0014$), and DCI vs. DHI or DSI ($p=0.0001$).

Values of electrical conductivity (Table 9) for surface soils of DCI plots were in the range where moderately-tolerant crops would be expected to suffer reduced productivity (Sposito, 1989). Compost applications in our study may have caused elevated levels of soluble salts shortly after the plots were established.

Soil temperature

Overall treatment effects for temperature were significant ($p=0.010$). Significant contrasts between D and DHS ($p=0.005$), and between DHS and DHI (0.0138) indicated that daytime soil temperatures in mid summer (Figure 3) were lower under the hog mulch than for the other treatments. A surface mulch of wood chips also reduced daytime soil temperature on rehabilitated landings in central British Columbia (Bulmer 2000).

Daytime soil temperature was also affected by decompaction (p=0.0103), with untreated plots having lower temperatures than those that were simply decompacted.

Tree growth response to soil temperature changes depends on the tree species, but the minimum temperature for root growth appears to be in the range 0 to 7 °C (Sutton 1991) with root growth becoming slower at temperatures below 5 °C (Orlander et al. 1990). Assuming that root growth occurs whenever daytime temperatures are above 7 °C, all of the treatment plots in the IDF indicated a potential growing season of approximately 180 days during 2000.

Water content

Water content varied with sampling date (p=0.0005). Levels declined from maximum values in spring to the lowest levels in August, before recovering slightly by October (Figure 5). Overall treatment effects for water content were significant ($p<0.0001$), as were time effects ($p<0.0001$) and the treatment*time interaction ($p<0.0001$). Separate contrasts for spring and summer conditions (Table 10) indicated that soils treated with hog fuel had higher soil moisture content, especially when the hogfuel was applied as a mulch (Figure 4), which we attribute to reduced evaporation from the soil surface. Other organic amendments have also been shown to increase soil water holding capacity. Zebarth et al (1999) showed that incorporation of biosolids and manure compost to a loamy sand agricultural soil increased water-holding capacity.

In these sandy loam soils, values for volumetric water content below 6-10 % (Table 4) indicate severe moisture stress for tree seedlings. Trees growing on the DCI, DSI, U and D plots may have experienced extended periods of low soil water availability during the 2000 growing season, while plots receiving hog fuel as a surface mulch appear to have had more available soil moisture.

Soil mechanical resistance

Overall treatment effects for soil mechanical resistance were significant ($p<0.001$), as were time effects ($p=0.0098$) and the treatment*time interaction ($p<0.001$). Results of separate analyses for spring and summer (Table 10) indicate that addition of woodwaste, either as a mulch or incorporated, reduced soil mechanical resistance compared to untreated plots or those that were simply decompacted. Addition of topsoil also resulted in lower soil resistance in both spring and summer.

Soil mechanical resistance increased from minimum values in the spring to reach maximum levels in summer, then declined again in the fall. The highest values of soil mechanical resistance occurred on D plots, while the lowest values were observed for the DCI treatment. The results for D plots were unexpected in view of common perception that simple tillage of coarse-textured soils often leads to successful rehabilitation. Our results indicate that texture class can only be used as a general guide to a soil's response to tillage, and factors such as organic matter content and more detailed descriptions of the particle size distribution may need to be considered. Plots treated with decompaction

alone had the lowest soil moisture content of all plots, which also likely contributed to higher values of soil resistance.

Soil moisture had the greatest effect on soil mechanical resistance in U, D, and DHS plots (Table 11). For U and D, these results may reflect relatively uniform soil physical conditions (i.e. no pockets of added wood waste) other than soil moisture. Soil bulk density was also closely correlated with soil mechanical resistance (Table 11).

Values of soil mechanical resistance in excess of 2500 kPa are considered to limit the growth of plant roots (Greacen and Sands 1980). For U and D plots, values exceeded this threshold for long periods during the growing season, while for other plots soil mechanical resistance was above the threshold only during extremely dry soil conditions. Soil mechanical resistance may be a major factor affecting productivity on these soils, and it appears that addition of wood wastes or replacement of topsoil could reduce the number of days when soils are too strong to allow plant roots to penetrate.

Our results for soil resistance, combined with the information presented for aeration porosity (Table 4), support the conclusion of Froehlich and McNabb (1984) that soil strength is more likely to limit root growth and forest productivity on these compacted coarse-textured soils, and limitations posed by inadequate aeration would be less likely.

SUMMARY AND CONCLUSIONS

Addition of wood residues reduced bulk density and soil strength, and also improved soil water status. These effects were most obvious when the residues were incorporated into the surface soil layer. Although the C content of soils receiving amendments was higher than for untreated soils, or soils that were simply tilled, levels of available N, P, and K were not affected in a major way by the addition of hog fuel, sortyard waste, or topsoil. With the exception of compost, and possibly topsoil, the major benefit of the woody amendments seems to be reflected in soil physical conditions, rather than site nutrition.

Elevated values of EC for plots amended with 1500 m^3/ha (470 t/ha) biosolids - woodwaste compost suggest that the high application rate of compost used in this study had the potential to induce osmotic stress for planted seedlings. These results illustrate the need for complete characterization of soil amendments before determining application rates.

Added wood wastes tended to reduce daytime temperatures and increase water content, which may have improved growing conditions for planted trees, as moisture content on many of the plots during the summer months was likely low enough to severely limit water uptake.

Soil mechanical resistance was strongly affected by the treatments. Values of soil mechanical resistance exceeded the growth-limiting threshold for untreated soils and those that were simply decompacted for most of the growing season. Values of soil

resistance were lower in plots amended with wood waste or topsoil than for plots that were untreated or simply decompacted. Since it appears that soil mechanical resistance may have been a limiting factor even at parts of the year when soil moisture was within the available range, the effect of wood waste on soil mechanical resistance is expected to provide a positive benefit for seedlings growing at this site.

Early results show that addition of wood waste can have positive impacts on soil properties, and these materials may have a place in soil rehabilitation efforts. Successful use of these materials depends on an understanding of their characteristics, along with the method of application.

ACKNOWLEDGEMENTS

We acknowledge the continuing support of Cindy Prescott who was principle investigator on the larger study of the use of woodwaste for rehabilitation . Candis Staley provided technical assistance throughout the project. Weyerhaeuser, Okanagan Falls (Steve Jones and Ed Collen) supported the study by providing harvest records and hauling the wood wastes. Soil samples were analyzed at the BC Ministry of Forests Research Branch Analytical Laboratory in Victoria. Funding for this project was provided by Forest Renewal BC

REFERENCES

Andrus, C. W. and Froehlich, H. A. 1983. An evaluation of four implements used to till compacted forest soils in the Pacific northwest. Oregon State University, College of Forestry. Res Bull No 45.

A.S.T.M. 2001Test method D698-00a Standard test methods for laboratory compaction characteristics of soil using standard effort (12,400 ft-lbf/ft3 (600kN-m/m3)). American Society for Testing and Materials.

Beauchemin, S., N'Dayegamiye, A., and Laverdiere, M.R. 1990. Effets d'apport d'amendements ligneaux frais et humifies sur la production de pomme de terre et sur la disponibilite de l'azote en sol sableux. Can. J. Soil Sci. 70:555-564.

Brady, N.C. 1984. The nature and properties of soil. 9th edition. MacMillan Publishing Co. New York.

Bremner, J.M., 1996. Nitrogen Availability Indexes. pages 1324-1345 *In* Methods of Soil Analysis, Part 2. Black, C.A. (Ed.) Soil Sci. Soc. Am. Madison, WI.

Bulmer, C. 1998. Forest soil rehabilitation in British Columbia: a problem analysis. B.C. Min. For., Land Manage. Handb. 44. 45 p.

Bulmer, C. 2000. Reclamation of forest soils with excavator tillage and organic amendments. For. Ecol. Mgmt. 13:157-163.

Bulmer, C. and M. Krzic, M. 2003. Soil properties and lodgepole pine growth on rehabilitated landings in northeastern British Columbia. Cdn, J. Soil Science 83:465-474.

Campbell, A.G., Folk, R.L., and Tripepi, R.R. 1994. Amended and composted log yard fines as a growth medium for crimson clover and red top grass. Commun. Soil Sci. Plant Anal. 25:2439-2454.

Carter, M.R. 1990. Relative measures of soil bulk density to characterize compaction in tillage studies of fine sandy loams. Can. J. Soil Sci. 70:425-434

Culley, J.L.B., 1993. Density and Compressibility. pages 529-540 *In* M.R. Carter (Ed.) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, FLA.

Daddow, R.L., and Warrington, G.E. 1983. Growth-limiting bulk densities as influenced by soil texture. Report WSDG-TN-00005. United States Dept. Agriculture, Forest Service, Watershed Systems Development Group, Fort Collins, CO.

da Silva, A.P., B.D. Kay, and E. Perfect. 1997. Management versus inherent soil properties effects on bulk density and relative compaction. Soil Tillage Research 44:81-93.

Delta-T Devices, 1999. ThetaProbe soil moisture sensor Type ML2x. User Manual. Delta-T Devices Ltd. Cambridge England.

Federer, C.A., Turcotte, D.E., Smith, C.T., 1993. The organic fraction - bulk density relationship and the expression of nutrient content in forest soils. Can.. J. For. Res. 23: 1026-1032.

Folk, R. L., and Campbell, A. G. 1990. Physical and chemical properties of classified logyard trash: a mill study. Forest Products Journal 40(4):22-24.

Froehlich H.A. and D.H. McNabb, 1984. Minimizing soil compaction in Pacific Northwest forests. p. 159-192 In E.L. Stone (ed.), Forest soils and treatment impacts. Proc. 6th North Am. Forest Soils Conference

Gouin, F. R., Link, C. B., and Kundt, J. F. 1978. Forest seedlings thrive on composted sludge. Compost Science/Land Utilization 19:28-30.

Greacen, E. L., and Sands, R. 1980. Compaction of forest soils: a review. Aust. J. Soil Res. 18:163-189.

Hallsby, G. 1995. Field performance of outplanted Norway spruce: effects of organic matter amendments and site preparation. Can. J. For. Res. 25:1356-1367.

Hendershot, W.H. and Duquette, M., 1986. A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Sci. Soc. Am. J. 50:605-608.

Hendershot, W.H., Lalande, H., Duquette, M., 1993. Soil Reaction and Exchangeable Acidity. pages 141-146 *In* M.R. Carter (Ed.) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, FLA.

Kalra, Y.P. and Maynard, D.G., 1991. Methods Manual for Forest Soil and Plant Analysis. Forestry Canada, Information Report NOR-X-319

Land Resources Network, 1993. Organic materials as soil amendments in reclamation: a review of the literature. Report RRTAC 93-4. Alberta Conservation Reclamation Council. Edmonton.211p.

Lloyd, D., Angove, K., Hope, G., and Thompson, C. 1990. A guide to site identification and interpretation for the Kamloops Forest Region. Part 1. British Columbia Ministry of Forests. Research Branch, Land Management Handbook 23.

McNabb, D. H. 1994. Tillage of compacted haul roads and landings in the boreal forests of Alberta, Canada. For. Ecol. Mgmt. 66:179-194.

McGill, W.B., and Figueirdo, C.T., 1993. Total nitrogen. pages 201-212 *In* M.R. Carter (Ed.) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, FLA.

Orlander, G., Gemmel, P., and Hunt, J. 1990. Site preparation: a Swedish overview. Report No. 105. Forest Resource Development Agreement. British Columbia Min. Forests. Victoria.

Plotnikoff, M. R. , C. E. Bulmer, and M. G. Schmidt. 2002. Soil Properties and Tree Growth on Rehabilitated Forest Landings in the Interior Cedar Hemlock Biogeoclimatic Zone: British Columbia. For. Ecol. Mgmt. 170:199-215.

Powers, R. F. 1980. Mineralizable soil nitrogen as an index of nitrogen availability to forest tress. Soil Sci. Soc. Am. J. 44:1314-1320.

Ringe, J.M., and D.H. Graves, 1990. Mulches derived from wood: an economic comparison of two materials used to reclaim surface mines. Forest Products J. 40(9):35-38.

Sanborn, P., C. Bulmer, and D. Coopersmith, 200x. Use of wood waste in rehabilitation of landings on fine-textured soils, central interior British Columbia, Canada. West. J. Appl. In press

Sheldrick, B.H. and C. Wang, 1993. Particle size distribution. pages 499-511 *In* M.R. Carter (Ed.) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, FLA.

Soil Survey Staff, 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agric. Handb. 436. U.S. Government Priniting Office. Washington, D.C.

Sposito, G. 1989. The Chemistry of Soils. Oxford University Press. New York.

Sutton, R. F. 1991. Soil properties and root development in forest trees: a review., Information Report O-X-412. Great Lakes Forestry Centre. Forestry Canada, Sault Ste. Marie.

Tiessen, H., Moir, J.O., 1993. Total and organic carbon. pages 187-200 *In* M.R. Carter (Ed.) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, FLA.

Wardle, D. A., Yeates, G. W., Watson, R. N., and Nicholson, K. S. 1995. Development of decomposer food web, trophic relationships, and ecosystem properties during a three-year primary succession in sawdust. Oikos 73:155-166.

Zebarth, B. J., Neilsen, G. H., Hogue, E., and Neilsen, D. 1999. Influence of organic wastes amendments on selected soil physical and chemical properties. Can. J. Soil Sci. 79:501-504.

Zeng, M., Campbell, A., G. Mahler, R. L. 1993. Log yard fines as a soil amendment: pot and field studies. Commun. SDoil Sci. Plant Anal. 24:2025-2041.

Table 1. Rehabilitation treatments at Okanagan Falls site.

Treatment	Tillage	Wood waste	Mulch thickness[1] (cm)	Incorporated to 25 cm ?
U	none	none		n/a
D	decompact to .75m	none		n/a
DT	decompact to .75m	topsoil	9.0 (2.1)	no
DSS	decompact to .75m	sort yard waste	10.9 (1.5)	no
DSI	decompact to .75m	sort yard waste	10	yes
DSI2	decompact to .75m	sort yard waste	20	yes
DHS	decompact to .75m	hog fuel	10.1 (3.4)	no
DHI	decompact to .75m	hog fuel	10	yes
DHI2	decompact to .75m	hog fuel	20	yes
DCI	decompact to .75m	biosolids–ww compost	15	yes

[1]numbers in brackets are standard deviations. Where no standard deviations are provided, the depth was estimated.

Table 2. Characteristics of wood wastes, obtained from samples collected prior to treatment.

	Bulk density kg m^{-3}	total C %	total N %	CN ratio	available P ppm	exchange K cmol(+) kg^{-1}	pH
Sort yard waste	551	21.3	0.13	160	120	1.7	5.7
Hog fuel	202	45.0	0.18	256	85	3.2	4.3
Compost	313	23.6	0.95	25	4108	6.2	4.4

Table 3. ANOVA summary table for bulk density, showing variance ratios (F), and p values

	0-10cm depth		10-20cm depth	
Source of variation	F	Pr > F	F	Pr > F
Treatment	8.85	0.0001	4.60	0.0005
U vs. all others	27.14	0.0001	10.82	0.0029
U vs. D	1.56	0.2224	0.02	0.8795
D vs. D+woodwaste	15.40	0.0006	10.92	0.0028
hog fuel vs. sort yard	6.00	0.0213	0.28	0.5988
DHS vs. DHI	9.40	0.0050	3.60	0.0688
DSS vs. DSI	8.70	0.0067	0.10	0.7584
DT vs. DHS or DSS	2.10	0.1589	0.00	0.9904
DCI vs. DSI or DHI	0.43	0.5176	1.43	0.2433
DT vs. D	26.84	0.0001	5.36	0.0288

Table 4. Water retention characteristics of the soils from landing 2. Values in brackets represent standard deviation.

	Water content v/v at Field capacity (33 J/kg)	Water content v/v at Wilting Point (1500 J/kg)	AWSC %	Aeration Porosity % (5 J/kg)
U	26.1 (1.5)	9.9 (2.6)	16.2 (1.8)	12.0 (5.5)
D	22.0 (2.3)	10.9 (4.0)	11.2 (2.8)	15.6 (3.6)
DT	23.2 (3.8)	6.7 (2.7)	16.5 (1.1)	12.9 (1.7)
DHS	28.8 (1.7)	9.6 (0.6)	19.2 (2.2)	13.2 (7.4)
DHI	25.6 (3.8)	8.4 (2.7)	17.2 (5.8)	24.2 (5.7)
DSS	24.2 (0.9)	8.9 (1.5)	15.2 (1.2)	19.2 (3.2)
DSI	21.3 (0.9)	6.2 (3.7)	15.1 (2.8)	16.2 (9.1)

Table 5. Mean values (standard deviations) of soil chemical properties and nutrient concentrations.

Treatment	Depth cm	Total C % [1]	Total N % [1]	CN Ratio [1]	Mineralizable N ppm [2]	Available P ppm [2]	SO_4-S ppm [2]
U	0 - 10	1.17 (0.62)	0.060 (0.025)	18.7 (2.8)	17.2 (2.2)	140.4 (14.0)	1.3 (0.1)
	10 - 20	0.57 (0.44)	0.026 (0.011)	20.2 (9.4)	6.4 (0.8)	99.2 (27.4)	0.6 (0.5)
	20 - 40	0.15 (0.05)	0.012 (0.004)	12.5 (1.5)	3.3 (1.3)	35.4 (7.3)	0.5 (0.5)
D	0 - 10	1.00 (0.60)	0.056 (0.026)	17.1 (3.1)	17.7 (9.7)	91.9 (29.1)	3.2 (3.8)
	10 - 20	0.38 (0.25)	0.025 (0.012)	14.0 (3.9)	10.6 (8.0)	70.9 (77.2)	2.7 (2.4)
	20 - 40	0.26 (0.06)	0.019 (0.005)	13.5 (3.1)	8.1 (0.4)	35.0 (27.3)	0.6 (0.7)
DT	0 - 10	1.93 (0.51)	0.085 (0.026)	23.1 (2.3)	23.0 (1.0)	168.2 (51.8)	1.8 (0.3)
	10 - 20	1.35 (0.81)	0.061 (0.034)	21.8 (1.7)	20.5 (2.8)	127.9 (10.4)	1.4 (0.2)
	20 - 40	0.47 (0.29)	0.027 (0.011)	16.3 (4.4)	10.2 (1.5)	107.5 (87.8)	0.5 (0.4)
DSS	0 - 10	2.94 (2.90)	0.079 (0.036)	32.9 (20.5)	5.6 (7.2)	117.3 (21.1)	1.8 (0.4)
	10 - 20	1.54 (1.10)	0.067 (0.034)	21.2 (5.7)	17.3 (5.1)	139.0 (25.6)	1.4 (0.4)
	20 - 40	1.08 (1.07)	0.056 (0.047)	17.6 (2.9)	23.5 (25.9)	91.5 (48.8)	1.4 (0.8)
DSI	0 - 10	2.43 (1.10)	0.074 (0.023)	32.0 (8.0)	0.7 (0.8)	99.6 (18.2)	1.6 (0.7)
	10 - 20	1.81 (1.11)	0.073 (0.019)	24.0 (9.6)	15.7 (21.1)	115.5 (9.5)	1.4 (0.2)
	20 - 40	0.71 (0.31)	0.035 (0.009)	19.9 (4.3)	8.1 (6.6)	72.6 (16.1)	1.0 (0.5)
DSI2	0 - 10	3.87 (1.78)	0.083 (0.025)	44.1 (9.7)	0.1 (0.2)	66.7 (12.0)	1.3 (0.1)
	10 - 20	3.36 (1.87)	0.094 (0.042)	34.5 (12.9)	1.5 (1.6)	77.0 (14.7)	1.7 (0.3)
	20 - 40	0.91 (0.84)	0.045 (0.037)	18.7 (3.5)	12.2 (4.9)	105.9 (65.1)	0.8 (0.2)
DHS	0 - 10	1.59 (1.00)	0.070 (0.031)	21.8 (5.1)	15.7 (4.2)	125.5 (13.5)	1.7 (0.4)
	10 - 20	1.03 (0.63)	0.051 (0.028)	19.5 (4.1)	14.6 (5.4)	108.4 (6.1)	1.6 (0.2)
	20 - 40	0.33 (0.16)	0.021 (0.008)	14.6 (3.4)	8.1 (7.8)	44.0 (34.2)	0.9 (0.2)
DHI	0 - 10	2.85 (2.45)	0.072 (0.058)	39.6 (12.4)	0.0 (0.0)	93.0 (67.3)	1.3 (0.6)
	10 - 20	1.56 (1.19)	0.049 (0.030)	30.5 (12.3)	3.2 (2.8)	94.3 (51.4)	1.0 (0.5)
	20 - 40	0.27 (0.17)	0.020 (0.010)	13.0 (1.6)	2.9 (2.0)	57.6 (71.8)	0.6 (0.1)
DHI2	0 - 10	3.06 (1.55)	0.064 (0.021)	58.0 (30.4)	0.8 (0.8)	91.7 (17.3)	1.0 (0.2)
	10 - 20	3.56 (3.07)	0.066 (0.037)	47.7 (17.3)	1.0 (1.7)	112.6 (15.5)	1.0 (0.4)
	20 - 40	6.02 (5.79)	0.083 (0.067)	63.4 (25.3)	1.6 (1.6)	110.2 (50.0)	8.4 (11.3)
DCI	0 - 10	5.68 (3.95)	0.334 (0.249)	17.3 (1.5)	132.0 (78.0)	842.1 (369.7)	63.4 (58.2)
	10 - 20	4.33 (2.93)	0.254 (0.172)	17.0 (1.4)	123.3 (77.9)	679.3 (166.1)	47.7 (38.8)
	20 - 40	1.28 (1.04)	0.088 (0.069)	14.1 (1.0)	26.6 (18.0)	192.6 (87.1)	13.1 (2.5)

[1] Except for occasional missing values, n= 9 for 0-10cm and 10-20cm depth, and n=3 for 20-40cm depth.
[2] n=3

Table 6. ANOVA summary table for total C, N, and CN ratio, showing variance ratios (F), and p values for significant contrasts only.

	0-10cm depth		10-20 cm depth		20-40 cm depth	
Source of variation	F	Pr > F	F	Pr > F	F	Pr > F
Carbon						
Treatment	3.51	0.0031	4.34	0.0007	2.59	0.0189
U vs. all others	5.41	0.0280	6.54	0.0167	1.09	0.3071
D vs. D+wood waste	6.18	0.0197	8.38	0.0076	1.27	0.2698
DCI vs. DSI or DHI	7.85	0.0095	6.55	0.0167	0.36	0.5546
DT vs. D	4.16	0.0517	1.88	0.1826	0.39	0.5390
Nitrogen						
Treatment	4.34	0.0007	6.14	0.0001	1.82	0.0941
U vs. all others	1.14	0.2958	4.93	0.0353	2.40	0.1336
DCI vs. DSI or DHI	37.52	0.0001	42.24	0.0001	6.04	0.0209
CN ratio						
Treatment	8.39	0.0001	4.65	0.0004	0.03	0.8553
U vs. all others	9.90	0.0041	2.12	0.1572	3.87	0.0599
D vs. D+wood waste	22.31	0.0001	11.80	0.0020	5.45	0.0276
hog fuel vs. sort yard	2.19	0.1514	6.29	0.0187	8.33	0.0077
DHS vs. DHI	8.31	0.0078	2.56	0.1215	0.08	0.7818
DCI vs. DSI or DHI	20.99	0.0001	6.78	0.0150	0.11	0.7443
DT vs. D	6.52	0.0169	1.10	0.3044	0.47	0.4972

Table 7. ANOVA summary table for mineralizable N, available P, SO4 – S, and exchangeable K, showing variance ratios (F), and p values.

	0-10 cm depth		10-20 cm depth		20-40 cm depth	
Source of variation	F	Pr > F	F	Pr > F	F	Pr > F
Mineralizable N						
Treatment	7.37	0.0001	6.06	0.0001	1.93	0.0748
U vs. all others	0.04	0.8454	1.25	0.2747	1.72	0.2015
DCI vs. DSI or DHI	75.38	0.0001	61.68	0.0001	8.52	0.0072
Available P						
Treatment	10.77	0.0001	24.35	0.0001	2.37	0.0297
U vs. all others	0.34	0.5635	3.23	0.0840	2.76	0.1088
DCI vs. DSI or DHI	107.27	0.0001	233.38	0.0001	9.67	0.0045
SO_4 – S						
Treatment	3.42	0.0037	4.33	0.0007	4.34	0.0007
U vs. all others	0.48	0.4925	0.79	0.3829	1.39	0.2495
DCI vs. DSI or DHI	32.19	0.0001	40.44	0.0001	31.45	0.0001
Exchangeable K						
Treatment	2.10	0.0516	2.84	0.0113	1.53	0.1730
U vs. all others	1.43	0.2419	3.54	0.0713	2.25	0.1456
DCI vs. DSI or DHI	16.40	0.0004	14.20	0.0009	0.30	0.5858

Table 8. Mean values (standard deviations) for soil chemical properties

Treatment	Depth cm	pH (H_2O)	Total CEC cmol(+) kg^{-1}	Ca cmol(+) kg^{-1}	K cmol(+) kg^{-1}	Mg cmol(+) kg^{-1}
U	0 – 10	5.9 (0.4)	4.0 (1.4)	2.9 (1.3)	0.38 (0.09)	0.56 (0.10)
	10 – 20	6.1 (0.3)	2.9 (1.3)	2.1 (1.1)	0.29 (0.11)	0.42 (0.20)
	20 – 40	6.3 (0.2)	2.1 (0.2)	1.5 (0.1)	0.13 (0.04)	0.39 (0.09)
D	0 – 10	5.9 (0.4)	4.5 (1.1)	3.1 (0.8)	0.44 (0.19)	0.80 (0.34)
	10 – 20	6.0 (0.5)	3.5 (1.9)	2.4 (1.4)	0.23 (0.02)	0.76 (0.52)
	20 – 40	6.2 (0.0)	3.9 (2.4)	2.7 (1.8)	0.21 (0.05)	0.90 (0.60)
DT	0 – 10	5.9 (0.2)	6.9 (1.3)	5.3 (1.1)	0.43 (0.16)	0.96 (0.06)
	10 – 20	5.9 (0.2)	4.5 (0.3)	3.3 (0.2)	0.38 (0.12)	0.64 (0.10)
	20 – 40	6.0 (0.4)	2.7 (0.5)	1.9 (0.5)	0.25 (0.15)	0.47 (0.07)
DSS	0 – 10	6.3 (0.3)	7.3 (2.9)	5.7 (2.5)	0.46 (0.18)	1.04 (0.34)
	10 – 20	6.1 (0.2)	4.8 (1.2)	3.6 (1.0)	0.41 (0.07)	0.67 (0.17)
	20 – 40	5.7 (0.6)	4.0 (1.7)	2.9 (1.1)	0.29 (0.12)	0.58 (0.29)
DSI	0 – 10	6.2 (0.1)	7.0 (2.2)	5.3 (1.6)	0.54 (0.25)	0.92 (0.23)
	10 – 20	6.1 (0.3)	5.8 (2.4)	4.3 (1.7)	0.53 (0.25)	0.76 (0.25)
	20 – 40	6.2 (0.2)	3.7 (0.8)	2.7 (0.9)	0.39 (0.24)	0.48 (0.05)
DSI2	0 – 10	6.3 (0.2)	11.2 (4.0)	8.9 (3.4)	0.52 (0.04)	1.63 (0.54)
	10 – 20	6.4 (0.2)	10.5 (5.0)	8.4 (4.2)	0.53 (0.05)	1.48 (0.70)
	20 – 40	6.2 (0.3)	4.6 (2.6)	3.5 (2.1)	0.35 (0.27)	0.56 (0.27)
DHS	0 – 10	6.2 (0.1)	5.3 (2.5)	3.9 (2.1)	0.55 (0.35)	0.75 (0.30)
	10 – 20	6.3 (0.1)	4.4 (1.6)	3.1 (1.3)	0.56 (0.50)	0.63 (0.23)
	20 – 40	6.3 (0.1)	3.2 (0.9)	2.2 (0.7)	0.19 (0.06)	0.64 (0.23)
DHI	0 – 10	6.0 (0.3)	5.6 (2.2)	4.0 (1.7)	0.56 (0.28)	0.85 (0.10)
	10 – 20	6.1 (0.2)	3.9 (1.6)	2.9 (1.4)	0.42 (0.19)	0.57 (0.10)
	20 – 40	6.3 (0.2)	3.6 (2.2)	2.5 (1.5)	0.25 (0.12)	0.77 (0.63)
DHI2	0 – 10	5.9 (0.1)	4.8 (0.8)	3.3 (0.6)	0.52 (0.16)	0.76 (0.03)
	10 – 20	5.9 (0.0)	4.7 (2.1)	3.3 (1.7)	0.52 (0.18)	0.74 (0.25)
	20 – 40	6.0 (0.1)	7.0 (4.1)	4.9 (2.6)	0.79 (0.71)	1.10 (0.67)
DCI	0 – 10	5.1 (0.3)	12.7 (8.9)	7.4 (4.9)	1.34 (0.92)	3.58 (2.80)
	10 – 20	5.3 (0.2)	9.6 (4.8)	6.0 (3.1)	0.97 (0.40)	2.39 (1.21)
	20 – 40	5.6 (0.3)	5.7 (2.5)	4.2 (2.3)	0.39 (0.19)	1.02 (0.23)

n=3 for all elements and treatments

Table 9. Electrical conductivity (and standard deviation) of selected samples.

Treatment	Depth cm	Conductivity ms cm^{-1}
U	0 – 10	0.28 (0.00)
	10 – 20	0.23 (0.02)
	20 – 40	0.25 (0.01)
D	0 – 10	0.37
	10 – 20	0.26
	20 – 40	0.21
DSI2	0 – 10	0.77 (0.20)
	10 – 20	0.68 (0.19)
	20 – 40	0.41 (0.12)
DCI	0 – 10	3.14 (2.07)
	10 – 20	2.74 (1.24)
	20 – 40	2.12 (1.07)

n=3 for U and DCI plots. Samples from D plots were not replicated

Table 10. ANOVA summary table for soil moisture and resistance, showing variance ratios (F), and p values.

	Soil Moisture		Soil Resistance	
Source of variation	F	Pr > F	F	Pr > F
May 31, 2000				
Treatment	5.25	0.0002	3.68	0.0023
U vs all others	0.76	0.3922	5.2	0.031
U vs D	9.8	0.0043	2.74	0.1102
D vs D+woodwaste	17.2	0.0003	23.82	<.0001
hog vs sy	15.86	0.0005	0.4	0.5322
DHS vs DHI	5.56	0.0262	0.08	0.785
DSS vs DSI	0.43	0.517	0.35	0.5594
DT vs DHS or DSS	7.17	0.0127	0.32	0.5784
DCI vs DSI or DHI	2.44	0.1305	0.04	0.8443
DT vs D	9.56	0.0047	9	0.0059
August 29, 2000				
Treatment	5.78	<.0001	7.57	<.0001
U vs all others	3.05	0.0924	13.39	0.0011
U vs D	0.22	0.6407	4.5	0.0437
D vs D+woodwaste	2.91	0.1001	48.27	<.0001
hog vs sy	19.39	0.0002	0.62	0.4383
DHS vs DHI	19.42	0.0002	1.76	0.1961
DSS vs DSI	0.1	0.7554	0.08	0.7749
DT vs DHS or DSS	15.27	0.0006	0.37	0.5491
DCI vs DSI or DHI	1.78	0.1942	0.78	0.3838
DT vs D	0.02	0.8762	27.43	<.0001

Table 11. Pearson correlation coefficients and p values for relationships between soil resistance, bulk density, and moisture.

		U	D	DT	DSS	DSI	DSI2	DHS	DHI	DHI2	DCI
Soil Resistance vs. Moisture	r	-0.6574	-0.7780	-0.5098	-0.4924	-0.2927	-0.4378	-0.7344	-0.4280	-0.4237	-0.3452
overall r = -.4993 ; p = .0001	p	0.0001	0.0001	0.0003	0.0006	0.0511	0.0026	0.0001	0.0034	0.0037	0.0202
	n	45	45	45	45	45	45	45	45	45	45
		26-Apr-00	31-May-00	07-Jul-00	29-Aug-00	20-Oct-00					
	r	0.0881	-0.1751	0.5703	-0.1923	0.0438					
	p	0.3267	0.0499	0.0001	0.0310	0.6262					
	n	126	126	126	126	126					
		U	D	DT	DSS	DSI	DSI2	DHS	DHI	DHI2	DCI
Soil Resistance vs. Bulk Density	r	0.2164	0.0874	0.0729	0.3934	0.2501	-0.0434	0.2825	0.5628	0.2841	0.2187
overall r =.4134; p=.0001	p	0.1533	0.5679	0.6342	0.0075	0.0976	0.7769	0.0601	0.0001	0.0585	0.1490
	n	45	45	45	45	45	45	45	45	45	45
		26-Apr-00	31-May-00	07-Jul-00	29-Aug-00	20-Oct-00					
	r	0.4154	0.4633	0.5034	0.5612	0.5459					
	p	0.0001	0.0001	0.0001	0.0001	0.0001					
	n	125	125	125	125	125					

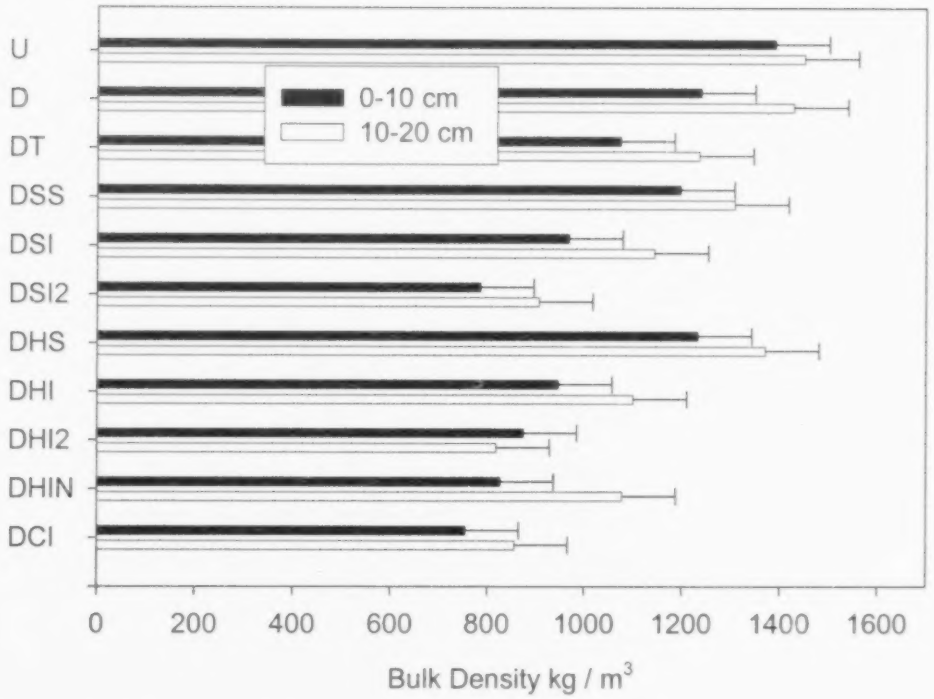

Figure 1. Bulk density of <2mm fraction. Error bars represent standard error of the mean.

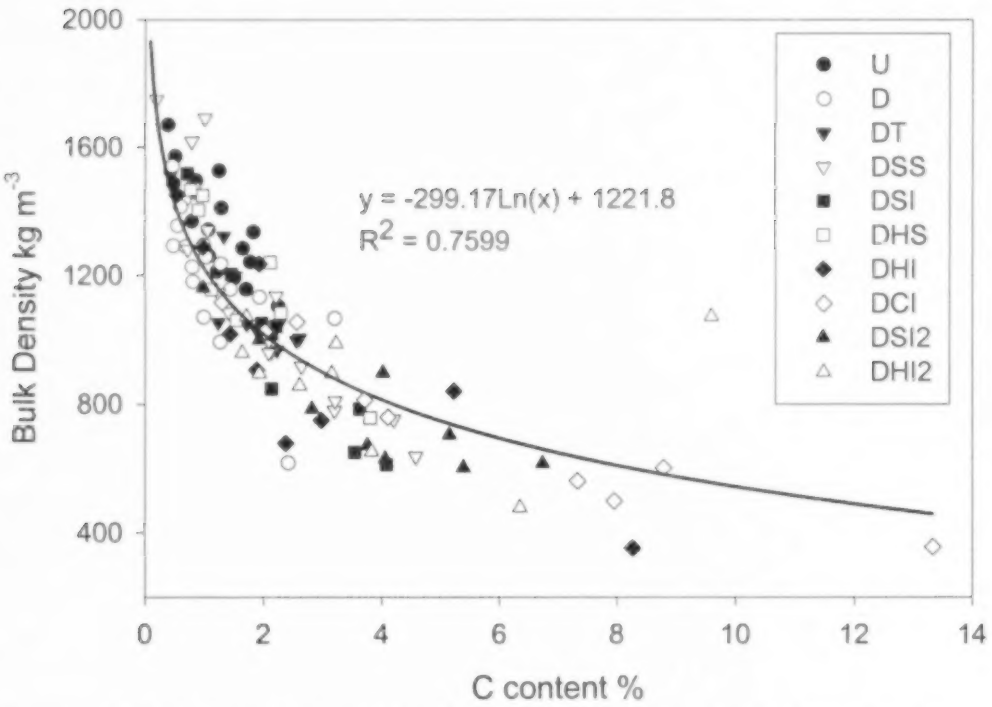

Figure 2. Carbon content and bulk density for surface (0-10cm) soils from all plots. Regression applies to all samples

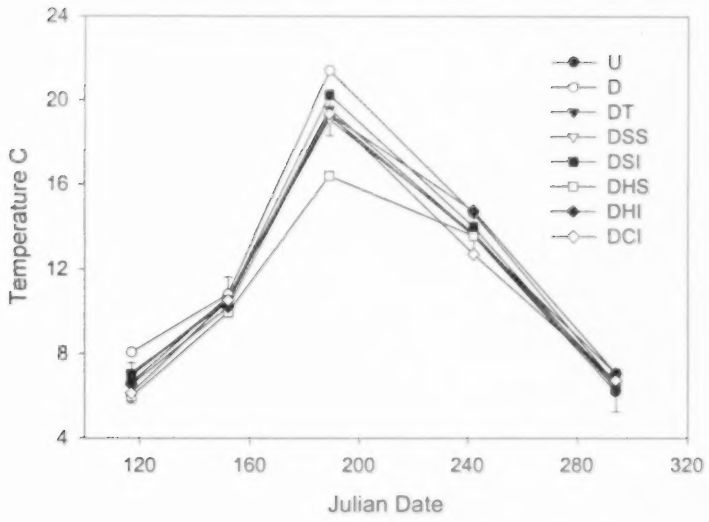

Figure 3. Daytime soil temperature April – Oct 2000. Error bars (U treatment only for clarity) represent standard error of the mean. n=3 for all measurements.

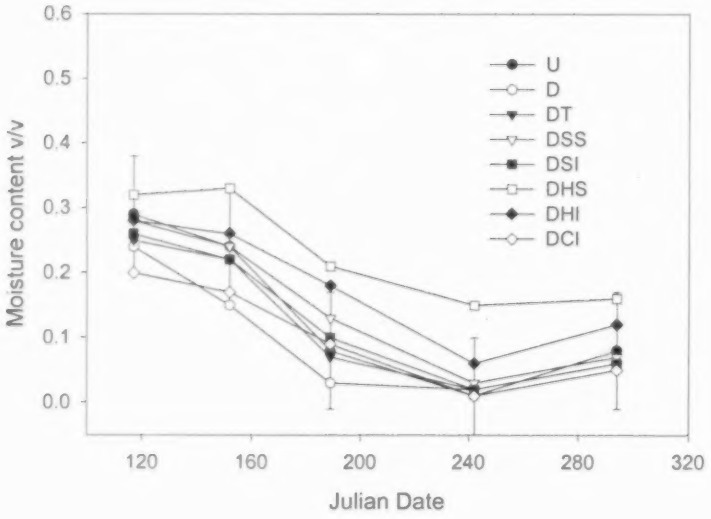

Figure 4. Volumetric water content April – Oct 2000. Measured with a theta probe. Error bars (U treatment only for clarity) represent standard error of the mean. n=3 for all measurements.

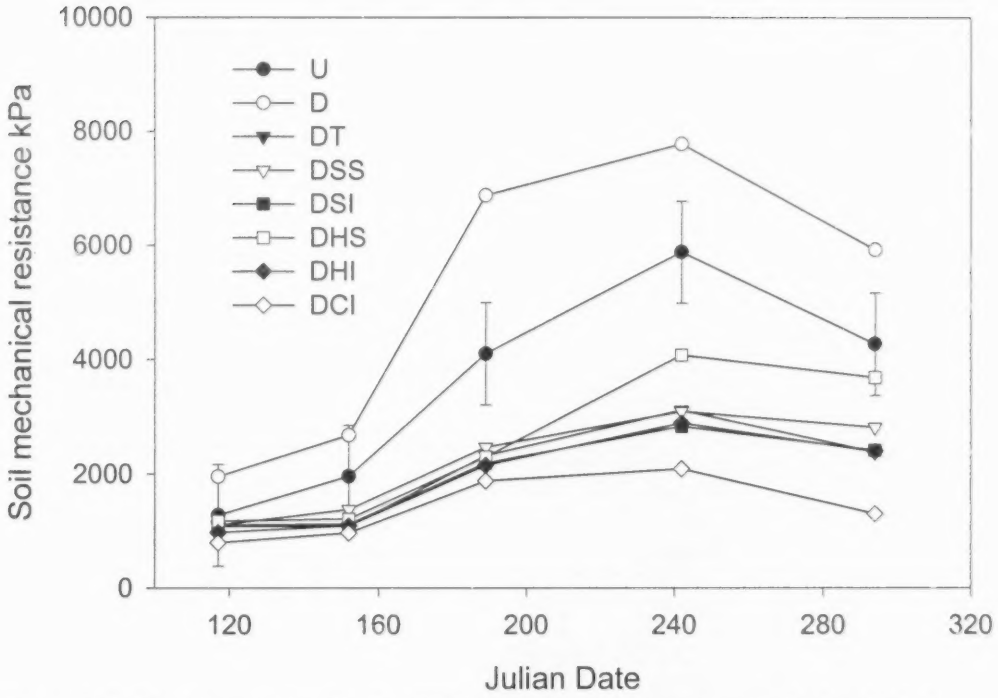

Figure 5. Soil resistance April – Oct 2000. Error bars (U treatment only for clarity) represent standard error of the mean. n=3 for all measurements.